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(71) Applicant: Hitachi Metals Ltd

(72) Inventors: Ohata Takumi et al.

1. Name of the Invention

Wear resistant alloy cast iron

2. Claimed range:

(1) Wear resistant cast iron contains MC,  $M_4C_3$ ,  $M_6C$ ,  $M_2C$  hard carbides and the area of graphite and carbide is greater than 20% in microstructure.

(2) The chemical composition of the alloy is given (by weight percent);

C: 2.5-4.0%, Si: 2.0-5.0%, Mn: 0.1-1.5%, Ni: 3-8.0%, Cr: less than 7.0%, Mo: 4-12.0%, V: 2.0-8.0%, the balance being Fe and impurities. This is the wear resistant alloy cast iron in claim 1.

(3) This wear resistant alloy further contains 2-8.0% Co based on claim 2.

3. Detailed description of the invention

(Related application field) The present invention is an alloy cast iron suitable for making rolling mill roll with high wear, seizure, and oxidation resistance.

(Current technology) It is very effective to increase wear resistance by precipitating hard carbides. Molybdenum and vanadium carbides have better wear resistance because of their higher hardness. On the other hand, graphite in cast iron has excellent thermal conductivity, which can reduce surface temperature rise due to friction to achieve better wear and seizure resistance. Moreover graphite is also a good solid lubricant. However, the strong carbide forming elements like molybdenum and vanadium will prohibit graphite formation, it is impossible for carbide and graphite to co-exist.

Nickel-chromium series alloy cast iron is the typical alloy containing both graphite and carbide. The carbide in the cast iron is primarily  $M_3C$  with a lower hardness. On the other hand, Japan patent 61-16415 disclosed an alloy cast iron for rolling mill roll containing chromium carbide or  $M_7C_3$  and  $M_{22}C_4$ , however, there are no other higher hardness type carbides like MC,  $M_4C_2$ ,  $M_6C$ ,  $M_8C$  and therefore can not further improve wear resistance. Using powder metallurgy method can produce alloys containing both graphite and carbide, however, the powder metallurgy method is very complex in production process and the cost is also high.

(Problems to be solved)

It was previous technical view that it was impossible to form graphite in cast irons containing strong carbides forming elements. The purpose of the present invention is to provide a method to produce a new type of wear resistant material containing both graphite and carbides from strong carbide forming elements.

(Methods to solve the problems)

The present invention finds the following new facts through carefully study;

- (1) There is an alloy cast iron in which both graphite and carbide exist at the same time. These are MC,  $M_4C_2$ ,  $M_6C$ , and  $M_2C$  type hard carbides which account for more than 20% total carbide area.
- (2) The chemical composition of the invention is given as (by weight percent)  
C: 2.5-4.0%, Si: 2.0-5.0%, Mn: 0.1-1.5%, Ni: 3-8.0%, Cr: less than 7.0%, Mo: 4-12.0%, V: 2.0-8.0%, the rest is iron with other inevitable purity elements. Cobalt can also be added between 2-8.0%.

[Principle]

The new material in the present invention contains more than 20% carbides plus graphite. This new material can utilize the benefits of both carbide and graphite; the high hardness carbides to increase wear resistance and the graphite to improve heat and seizure resistance due to its high thermal conductivity and self-lubricating property.

The followings are the reasons for the specific chemical composition of the alloy;

C: carbon can promote graphite formation and at the same time carbon is also the necessary element to form hard carbides. It is difficult to precipitate graphite plus poor wear resistance when carbon is lower than 2.5%. Excessive amount of carbides will deteriorate toughness when carbon is beyond 4.0%.

Si: Silicon can de-oxygen and also promotes graphite formation. It is necessary to contain at least 2.0% silicon. However, material will become very brittle when silicon is higher than 5.0%. It is necessary to have at least 1.0% silicon added as inoculation to promote graphite precipitation.

Mn: Manganese can remove oxygen from liquid metal. Mn can also remove sulfur to form MnS. There is no de-gassing effect when Mn is less than 0.1%, however, when Mn is higher than 1.5%, it will form residual austenite to lower down hardness.

Ni: Nickel can promote graphite precipitation and also improve heat resistance. It is necessary to have 1.8% nickel, however, it is difficult to have Bainite or martensite transformation to increase alloy hardness when nickel content is greater than 8.0%.

Cr: Chromium is effective to keep hardness of Bainite or Martensite. However, chromium will retard graphite formation and also forms  $M_7C_3$  and  $M_{22}C_8$  type chromium carbide. The wear resistance will decrease because the hardness of chromium carbides is lower compared to  $M_4C_2$ ,  $M_6C$  or MC type carbides. Chromium upper limit is 7%.

Mo: Molybdenum combines carbon to form  $M_2C$  or  $M_6C$  type carbides and it also exists as solid solute atoms to strengthen matrix. Therefore, molybdenum can improve wear resistance, high temperature hardness and also increase softening resistance at high temperature.

Vanadium is the necessary element to form MC type carbide to increase wear resistance. However, excessive amount of vanadium will retard graphite precipitation. Hence, vanadium

is between 2-8.0%.

Besides the above alloy elements, the present invention can also contain cobalt, an alloy element that can have secondary hardening to resist tempering softening, cobalt can improve heat resistance. However, excessive amount of cobalt will deteriorate toughness. Cobalt range should be between 2-8.0%.

Besides the above elements, the balance is iron with other inevitable impurities, which mainly consists of phosphor and sulfur. Phosphor should control within 0.15% for better toughness and sulfur should be less than 0.08% for the same reason.

When pouring into casting molds, it is necessary to add silicon for inoculation process. Silicon content in the inoculation process should be greater than 0.1% in order to promote graphite precipitation. When the amount is higher than 0.5%, it is difficult to dissolve into liquid metal and casting scrap rate will also increase.

#### Example 1

Sample A and B are inventive alloys. All sample alloys were melt using a high frequency induction furnace at 1600 °C temperature. When pouring, add 0.3% silicon using Ferro-silicon at 1100 °C to form a sample with 100 mm diameter and 100 mm in length. Check microstructure 15 mm underneath the outer diameter surface. Graphite and carbide were observed in all samples. The microstructure of sample B is illustrated in Figure 1, (1) is un-etched microstructure, (2) is etched microstructure. Flake or block type graphite can be observed and the graphite area is 2%. Graphite is also observed in Figure (2), there are block shaped MC carbide from vanadium and bone shaped  $M_6C$  type carbide. The area of these hard carbides is about 85% of total carbide area.

#### Example 2

Quench the samples at 1500 °C made from example 1, temper these samples at 500 °C. Table 1 shows the hardness after heat treatment. Machine the samples into miniature type roll with 60 mm in outer diameter and 40 mm in length as shown in Figure 3. Determine wear resistance of these samples in a rolling mill type wear tester.

Rolling mill type wear tester conditions:

Rolling material: SUS304

Deformation rate: 25%

Rolling speed: 150 m/min

Rolling material temperature: 900 °C

Rolling distance: 300 m

Roll cooling method: water cooling

The contact area between the roll and the rolling material shows wear marks, and oxidation and seizure area also show dimensional change. Sample wear was determined with a surface profilometer. In the same graph (1) is the profile of sample alloy B, (2) is

for sample alloy C. Table 1 summarizes the average depth of each sample roll.

From the above experimental results, the present invention samples A and B have a better wear resistance with much less worn area on the sample roll when compared with previous chromium carbide type cast iron roll. It is expected that the present invention can provide much better performance as rolling mill rolls whether in the bulk or composite forms as disclosed in Japan Patent 44-4903.

[Results of the invention]

The present invention creates a new microstructure with both graphite and carbide that do not exist in previous alloys. The inventive alloy has better wear, seizure, and oxidation resistance. Therefore castings made from the inventive alloy will have a significant improvement in various wear resistant components.

4. Description of the drawings

Figure 1 is the microstructure of inventive alloy sample. (1) is un-etched microstructure, (2) is the etched microstructure. Figure 2 is the cross-section after wear test, (1) is from the inventive sample, and (2) is the comparative sample. Figure 3 is the drawing to show rolling mill roll wear tester.

1: heat furnace; 2: rolling material; 3: rolling mill; 5: upper roll sample; 5' bottom roll sample.  
8: rewinder